

15. Rapid Weakening Experiment (RWEX)

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Significance and background

Though operational tropical cyclone (TC) intensity forecasting has improved in recent years (DeMaria et al. 2014), predicting rapid changes in the 1-minute maximum sustained wind (hereafter referred to as intensity) remains prone to error. While strides have been made to reduce error in forecasts of rapid intensification (RI; an intensity change of at least 30 kt in 24 h), little work has been done on over-water rapid weakening (RW; an intensity change of at least -30 kt in 24 h [Wood and Ritchie 2015]). Accurate forecasts of rapid changes in TC intensity near land and/or prior to landfall can significantly impact preparations made by marine interests and coastal communities. However, few RW events have been measured by aircraft, limiting observations to geostationary and infrequent polar satellite measurements.

Vertical wind shear is a major factor in weakening as shown by numerous studies (e.g., DeMaria 1996; Frank and Ritchie 2001; Wong and Chan 2004). Its role in RW is less obvious, as composite shear only marginally increased during RW in both the North Atlantic and eastern North Pacific (Wood and Ritchie 2015). Decreasing sea surface temperatures (SSTs) have also played a role in RW (Wood and Ritchie 2015), and a study that included Hurricane Rita (2005) demonstrated the need for better representation of the oceanic mixed layer for intensity forecasting (Jaimes and Shay 2009).

Other case studies of RW are limited: the examination of Hurricane Earl (Jaimes et al. 2015) focused on ocean and near-surface properties and the TC's response to changes in them, and an evaluation of Hurricane Lili (2002; Frederick 2003) placed the TC's RW in the context of historical events but not in the context of its environment. Zhang et al. (2007) explored the usefulness of satellite data in improving model forecasts of Hurricane Lili's RW, also suggesting that dry air intrusion contributed to RW. It is notable that both Lili and Rita rapidly intensified prior to rapidly weakening, and both TCs made landfall post-RW.

The RW of Hurricane Earl (2010; Jaimes et al. 2015) and Hurricane Patricia (2015) were sampled, but more data in more environments are needed to improve our understanding of the structural changes that occur during RW as well as the relationship of the rate of weakening to environmental factors such as dry air intrusion and decreasing SSTs (see Figures 15-1-15-2 for more examples). Better understanding of the physical processes and environments involved in RW should subsequently improve forecasting models such as the Statistical Hurricane Intensity Prediction Scheme (SHIPS; DeMaria and Kaplan 1999).

Aircraft observations of multiple weakening events are needed to better characterize the contribution of different negative environmental factors to the likelihood of RW and the overall rate of weakening in 24 h. Contrasting slower weakening with RW should highlight the differences in both TC structural evolution and the environment that contribute to weakening rates.

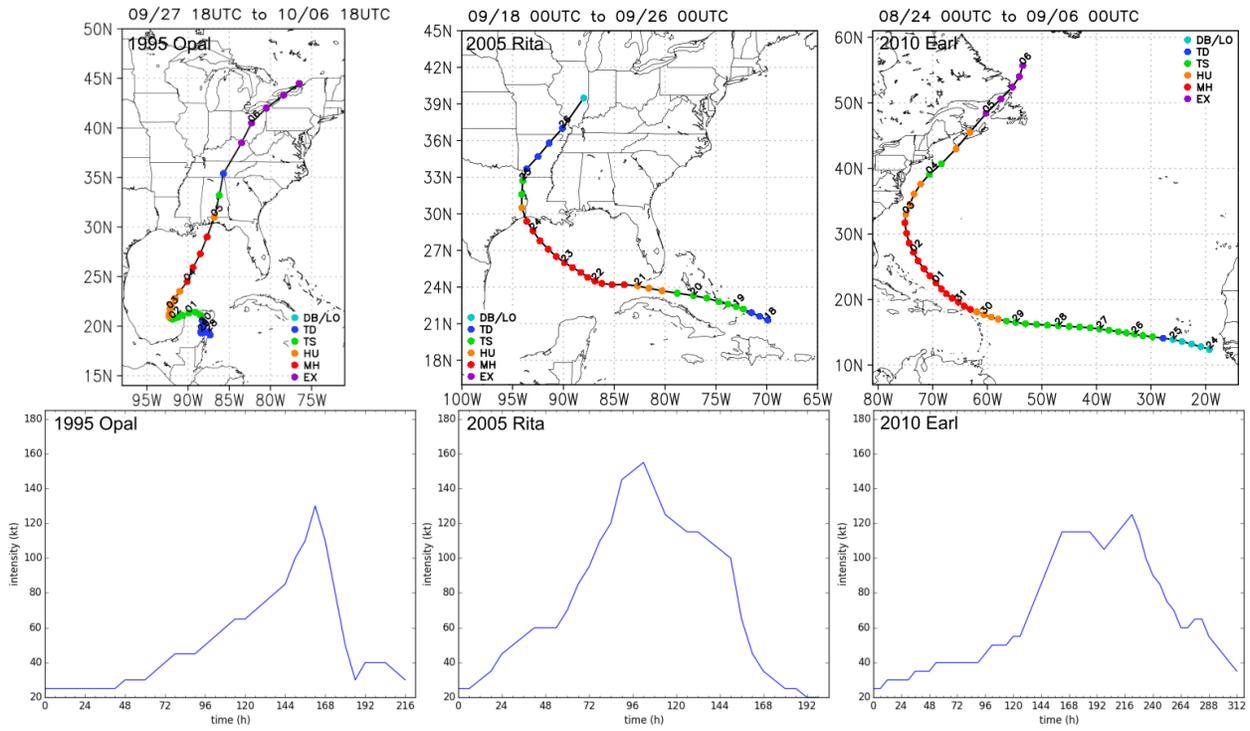


Figure 15-1. Three examples of rapid weakening near land in the North Atlantic.

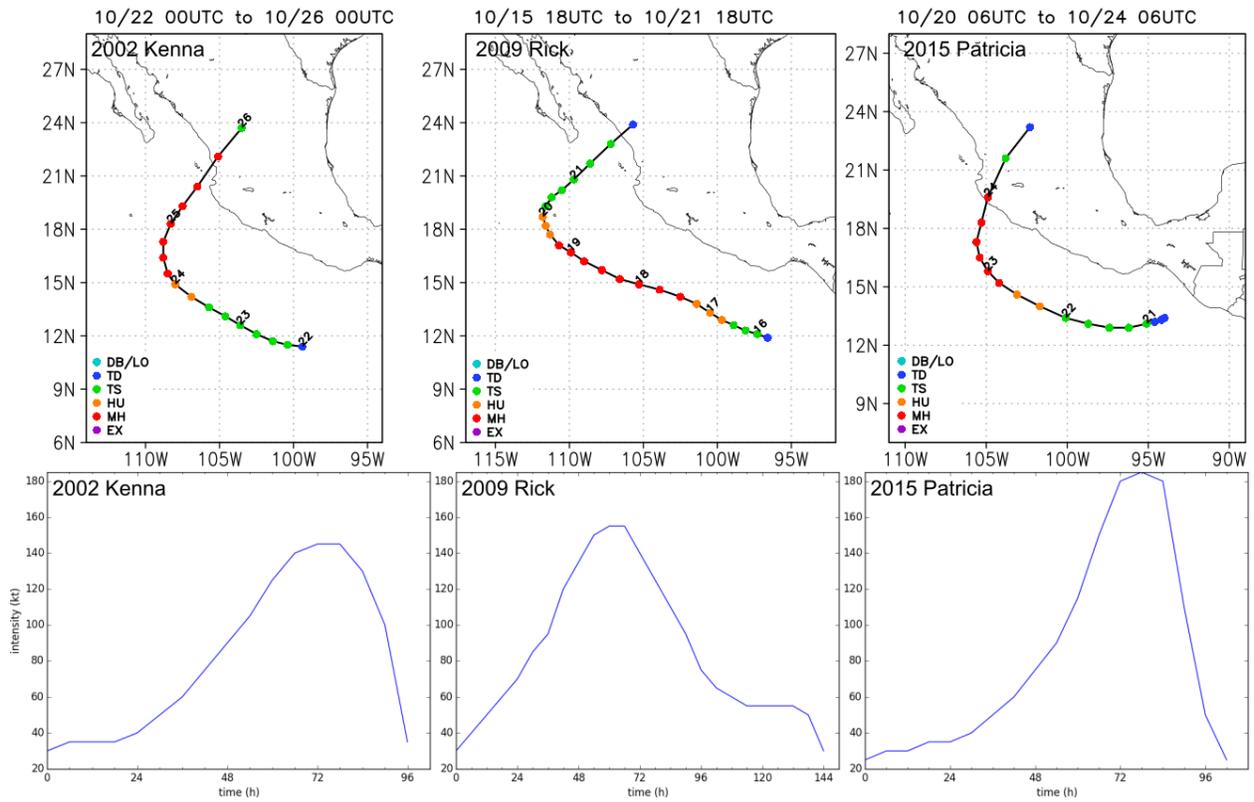


Figure 15-2. Three examples of rapid weakening near land in the eastern North Pacific.

Objectives

The main objective of this experiment is to examine the characteristics of both the TC and its environment prior to and during weakening, particularly RW. These observations will be analyzed in order to improve understanding of the physical processes and environmental factors involved in these events and explore avenues for improved forecast accuracy.

Observations of the ocean, of winds, and of thermodynamic variables taken by the G-IV and NOAA P-3 aircraft within the core of weakening and rapidly weakening TCs and their large-scale environments will enable the achievement of this objective. The best candidates for sampling will be TCs moving over cooler SSTs as well as increasing vertical wind shear. TCs that begin to entrain dry air as they move over cooler SSTs should also be sampled.

Hypotheses

- The three leading factors that cause RW are cooling SSTs, dry air intrusion, and increasing vertical wind shear.
- Of these three leading factors, cooling SSTs dominate due to their impact on inner core convection, making the storm more vulnerable to dry air intrusion and/or vertical wind shear.
- Observations spanning the core of the TC and its environment will improve our understanding of conditions that precede RW as well as occur during it, allowing us to investigate impacts such as the rate of erosion of the warm core and the role of core tilt.

Links to IFEX goals

- Goal 1: Collect observations that span the TC life cycle in a variety of environments for model initialization and evaluation
- Goal 3: Improve understanding of the physical processes important in intensity change for a TC at all stages of its lifecycle

Model evaluation component

Zhang et al. (2007) showed utility in adding satellite observations to improve model forecasts of RW. However, little work has been done that tests the addition of aircraft observations to model representation of these TCs that rapidly weaken over open ocean, both for intensity and structural evolution. Also, more oceanic observations, particularly for weakening TCs, may improve the capability of models to capture oceanic features that influence intensity (e.g., Jaimes and Shay 2009). The range of spatial scales at which data will be collected for weakening TCs in this experiment should provide a sufficient dataset by which to evaluate operational modeling systems, such as the ability of the models to capture changes in the TC structure.

Mission description

Systems expected to weaken over open-ocean will be targeted, such as those forecast to move over cooler SSTs. The best-case scenario would be to sample a TC that is also expected to entrain dry air and encounter increasing vertical wind shear beginning 24 h prior to the forecast onset of RW. Eastern Pacific TCs are of particular interest since many cases of RW occur in this basin. If missions are flown up to every 12 h from this point until the completion of RW (24 h after onset), the structural evolution leading up to and during the entire process should be captured. As many of these systems appear to undergo RI prior to RW, coordination with RAPX would be optimal.

To enable all of the desired observations, the NOAA P-3 and G-IV are required to fly simultaneously. Eye penetration is needed to obtain accurate samples of the current intensity as well as the structure of the inner core and the ocean below the center. Both AXBTs (if available) and dropsondes from the NOAA P-3 should be used every ~40 km for adequate sampling coverage. Larger intervals may not properly capture the variability in the storm's structure. An example flight pattern is provided in Figure 15-3.

The G-IV should follow the pattern shown in Figure 15-4 above 40000 ft. with dropsondes launched at 4 RMW, 5 RMW and 6 RMW (~200-500km) to measure characteristics of the near-storm environment. A secondary pattern for the G-IV is displayed in Figure 15-5 where dropsondes are deployed in each quadrant at those radii. Since it is a long flight (~9 hours), this pattern is ideal when the TC is within 1 hour of the deployment location. Using either pattern, these radii will enable the derivation of vertical wind shear and upper-level divergence, both having shown a relationship to RW. The use of dropsondes in this manner should also highlight the location and magnitude of any dry air entrainment that is occurring.

This experiment can also make use of observations from the NASA Global Hawk. If the G-IV is unavailable, tandem flights of the NASA Global Hawk and NOAA P-3 should capture much of the structural evolution during RW, especially if all instrumentation on board the Global Hawk can be utilized simultaneously within 600 km of the TC center (dropsondes, S-HIS, HIRAD, HIWRAP, and HAMSR).

Analysis strategy

This experiment is intended to support a multi-dimensional, multi-scale analysis of the conditions leading up to and during RW. Satellite observations will be used to evaluate the environmental conditions of the atmosphere and ocean surface during the experiment, as well as *in situ* observations such as ocean buoys when available. Examination of data measured in the inner core (Doppler radar reflectivity and vertical velocity) will show structural evolution as the TC weakens. Dropsonde data from the inner core and the environment will highlight the influence of environmental factors on the structure of the TC as it weakens, and ocean data will demonstrate the influence of changes in oceanic properties. Results from these analyses will be used to assess predictors that may improve the SHIPS model for rapidly weakening TCs.

References

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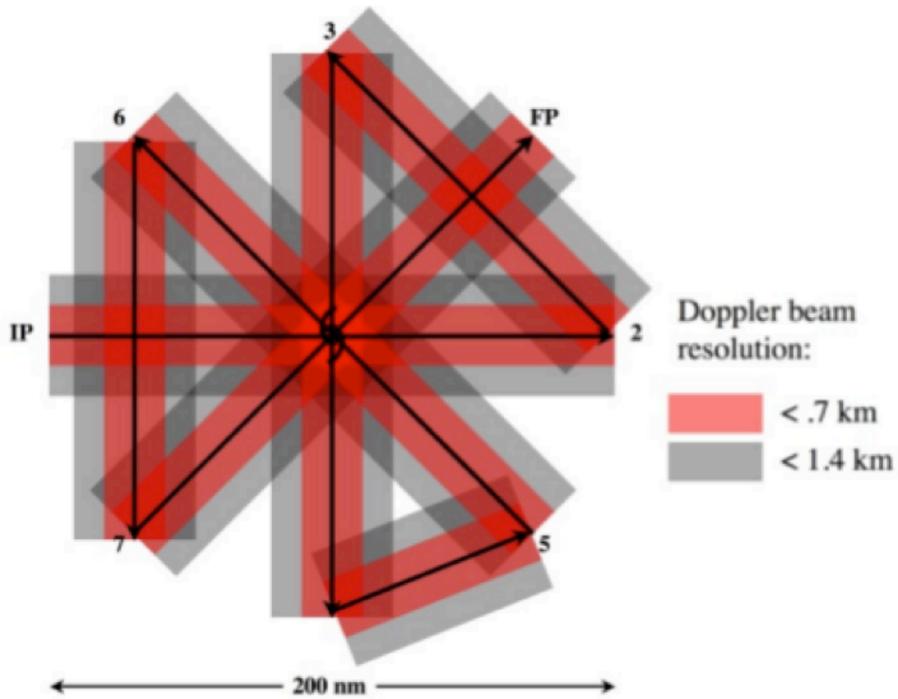


Figure 15-3. Sample rotated figure 4 pattern designed for the RAPX mission. Shading indicates the Doppler beam resolution at each location along the flight path. Dropsondes should be released at the turning, mid, and center points. An additional dropsondes should be released between the turn and mid points for each radial pass. If possible, release AXBTs coincident with dropsonde locations. Duration ~ 4 hours

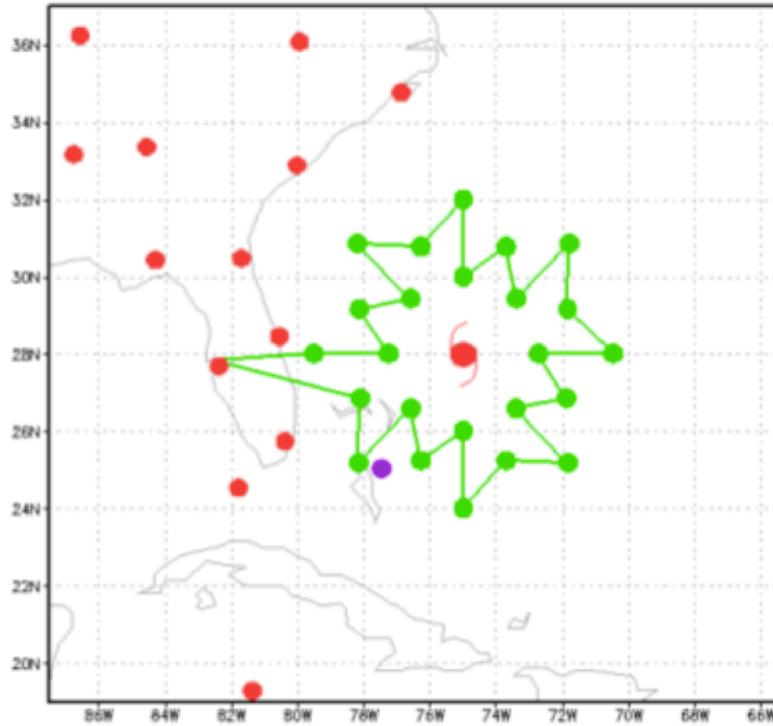
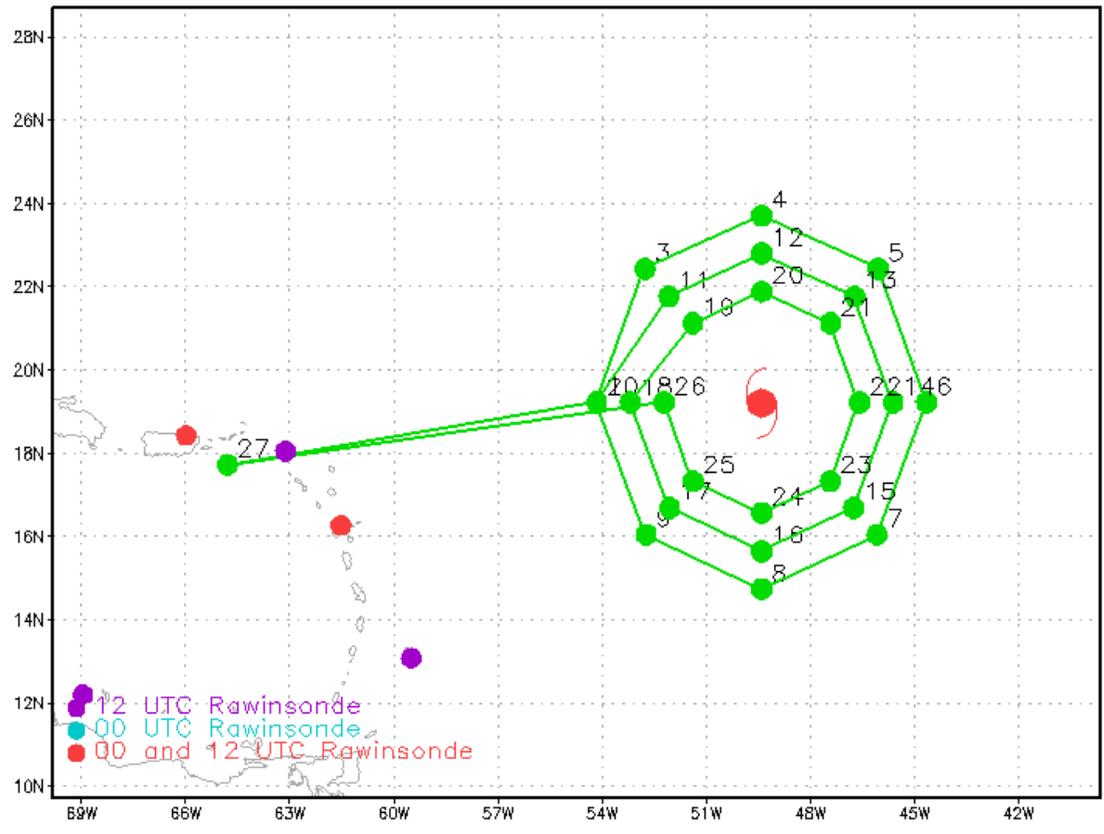


Figure 4. Sample G-IV flight pattern for the RAPX mission; Green dots indicate dropsonde release locations at radii of 220, 330, and 440 km relative to the TC center. Duration ~6 hours



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Figure 5. Sample G-IV flight pattern when TC is within 1-hour proximity to deployment location. Dropsondes are released with 45 degree spacing at 4, 5, and 6 RMWs (~200-500 km). Duration ~9 hours